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LOWTHRM:
A THERMAL FLUENCE CODE

THESIS

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AFIT/GNE/PH/80M-5

# LOWTHRM: A THERMAL FLUENCE CODE,

Master THESIS

Presented to the Faculty of the School of Engineering
of the Air Force Institute of Technology
Air University
in Partial Fulfillment of the
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Master of Science


by
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## Preface

I would like to express my appreciation to my advisor Capt. David Hardin for his patience and suggestions in the development of this thesis. I also wish to acknowledge my indebtedness to my wife, Carol, for her assistance in the preparation of this work and to thank her for her unselfish support and understanding throughout the days necessary to complete this work.

Chris R. Westbrook

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## Abstract

A Fortran computer program LOWTHRM is described for calculating nuclear thermal fluence incident upon a target area. Atmospheric transmissivity factors in the spectral region 0.25 to 28.5 microns are determined through use of the LOWTRAN5 computer code. The program provides a choice of six model atmospheres covering seasonal and latitudinal variations from sea level to 100 km, eight haze models, and accounts for molecular absorption, molecular scattering, and aerosol extinction. Atmospheric refraction, earth curvature effects, thermal scattering, and thermal ground reflection contributions are included.

# LOWTHRM:
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## I. Introduction

### Background

One of the unique characteristics of a nuclear detonation is the release of an enormous amount of energy in a small mass of material which ultimately results in the formation of a fireball. This fireball reradiates part of its energy as thermal radiation distributed over the ultraviolet, visible, and infrared regions of the spectrum. It is this thermal radiation that can cause a rapid heat buildup producing burns, charring, and possibly ignition of exposed materials (Ref. 9).

The energy flux of thermal radiation from a nuclear detonation decreases rapidly with increasing distance from the burst point. This is largely due to spherical divergence, but atmospheric factors such as absorption and scattering are also important. In fact, these atmospheric factors change the radiation incident upon a target from a direct fluence to more of a diffuse one. Therefore, a target receives radiation that has been scattered toward it as well as the radiation that has been directly transmitted from burst to receiver. Since thermal radiation calculations are important in predicting the survivability/vulnerability of Air Force systems, a model for calculating thermal fluence is essential to Air Force planning.

## Purpose

The purpose of this thesis is to develop a thermal fluence computer code. It will determine contributions from direct, scattered, and ground reflected sources incident upon a target area. Values for "exact" atmospheric transmission of radiation will be based upon the LOWTRAN5 Fortran computer code currently in use by the Air Force. To determine the validity of the developed code, results obtained will be compared against several models available for similar computations.

## Scope

In order to alter the LOWTRAN5 code to produce thermal fluences, a thorough study of the code and its variables must first be accomplished. Next, routines to calculate the weapon thermal efficiency and to weight the source spectrum must be added. Numerical integration techniques are then used to determine the direct, scattered, and ground reflected fluences incident on a receiver at various orientations. Finally, a User's Guide is included to document options available from the completed code.

## Development of the Report

In Chapter II, a short overview of the theory of thermal radiation from an air burst is presented. In this chapter the source is presented with a transmission model based on diffusion theory. The energy range of the thermal photons and mechanisms of interaction with the atmosphere are examined.

Chapter III discusses the LOWTRAN5 code upon which the available atmospheric models are based. In Chapter IV the LOWTHRM computer model is presented. It includes discussion of the thermal pulse and the unreacted, scattered, and ground reflected fluences. Chapter V compares results obtained from the finished code with other available models. Appendix A is the LOWTHRM User's Guide which may be reproduced and used as an aid in running the code. Appendix B contains sample output for several example cases.

## II. Theory of Thermal Radiation Phenomenon

### Source

The source of thermal radiation in a nuclear detonation is the fireball. For an air burst, the thermal radiation is emitted in two pulses which correspond to the apparent rise and fall of the fireball surface temperature. The first pulse is of very short duration and contains only about one percent of the total thermal radiation emitted. The second pulse contains the bulk of the thermal radiation and may last for several seconds depending upon the weapon yield (Ref. 9). The two pulses are illustrated in Figure 1.

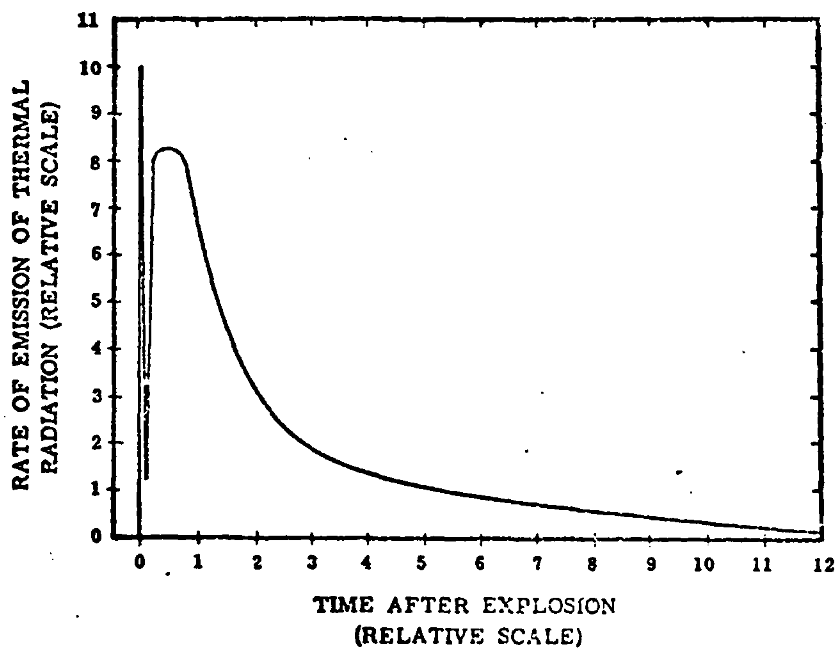


Fig. 1. Emission of Thermal Radiation in Two Pulses in an Air Burst (Ref. 9:41)

Because of its low yield, the first pulse can be neglected in thermal radiation calculations.

In order to construct an approximate source model, some simplifying assumptions must be made. The nuclear burst is considered to be a point isotropic source localized at the point of detonation. It is also assumed to emit radiation according to a Planckian blackbody distribution. Although studies made in various weapons tests have shown that the fireball does not behave exactly like a blackbody radiator, this distribution is close to the actual weapon spectrum (Ref. 9:305). To the extent of this report, the deviation from an ideal Planckian spectrum does not contribute a serious error to the calculations of thermal fluence.

## Transmission

The diffusion equation is used to develop the theory of transmission of thermal radiation. Assuming a homogenous atmosphere and all scatter as removal, the thermal radiation can be assumed to act like streaming particles. Taking into account the point source, the fluence, $F(r)$, is a function of the distance from the source. The diffusion equation is

$$\frac{dF(r)}{dr} + \frac{2}{r} F(r) + \mu F(r) = 0 \tag{1}$$

where $r$ is the distance from the source and $\mu$ is the total cross section. Rearranging Equation (1) and integrating from the fireball radius, $r_{fb}$, to the receiver, $R$, gives

$$\int_{r_{fb}}^{R} \frac{dF(r)}{F(r)} = - \int_{r_{fb}}^{R} \frac{2}{r}dr - \mu\int_{r_{fb}}^{R} dr \qquad (2)$$

which is

$$F(R) = \frac{(r^2_{fb}\,F(r_{fb}))\exp\ (-\mu(R-r_{fb}))}{R^2} \qquad (3)$$

Applying boundary conditions

$$\lim_{r \to r_{fb}} \ (4\pi r^2 F(r)) = Y \qquad (4)$$

where Y is the thermal yield

$$F(r_{fb}) = \frac{Y}{4\pi r^2_{fb}} \qquad (5)$$

Since the point source assumes $r_{fb}$ is zero, substituting Equation (5) into Equation (3) yields

$$F(R) = \frac{(Y)\exp(-\mu R)}{4\pi R^2} \qquad (6)$$

The expression $\exp(-\mu R)$ is the atmospheric transmittance, T. This transmittance is a function of many variables. However, if the effects of the atmosphere are ignored, Equation (6) reduces to

$$F = \frac{Y}{4\pi R^2} \qquad (7)$$

where F is the thermal fluence (energy per unit area), Y is the thermal yield (energy), and R is the path length between the burst and receiver (distance). The only attenuation in this case is spherical divergence given by $4\pi R^2$ (Ref. 12:4-6).

## Spectrum from an Air Burst

The range of thermal photon energies from the source is assumed to correspond to a 6000$^{\circ}$K Planckian distribution (Ref. 9:307). Using Planckian tables (Ref.23), the range from 0.25 to 28.5 microns contains approximately 99 percent of the thermal radiation emitted. This range can be divided into three broad bands; ultraviolet, visible, and infrared. Table I gives the band limits in terms of wavelength and frequency.

Table I

Broad Band Structure of Thermal Spectrum in an Air Burst

| BAND | WAVELENGTH (microns) | FREQUENCY (Hertz/Sec) |
|---|---|---|
| Ultraviolet | 0.25 - 0.4 | $1.2 \times 10^{15}$ - $7.5 \times 10^{14}$ |
| Visible | 0.4 - 0.7 | $7.5 \times 10^{14}$ - $4.3 \times 10^{14}$ |
| Infrared | 0.7 - 28.5 | $4.3 \times 10^{14}$ - $1.1 \times 10^{13}$ |

## Photon Interaction with the Atmosphere

Aerosol. Of course the transmission effects of the atmosphere cannot be ignored since this would predict fluences that are higher than can realistically be expected. In the visible and infrared portions of the spectrum, scattering effects drastically change atmospheric transmission. If the atmosphere were composed solely of air molecules, the knowledge of their scattering laws would be sufficient for

transmission calculations. However, the atmosphere also includes haze aerosol which is subject to other scattering laws. This aerosol is composed of all solid or liquid particles suspended in the atmosphere with sizes ranging from about 0.03 to 100 microns. Although aerosol concentrations are orders of magnitude less than molecular concentrations, the aerosols are very important in atmospheric transmission of radiation. These particles scatter and absorb radiation and affect the processes of atmospheric condensation resulting in the formation of clouds, snow, rain, and fog (Ref. 2). This scattering of thermal radiation is generally treated according to the classical theory developed by Gustav Mie (Ref. 22).

Molecular Scatter. At altitudes greater than five kilometers the aerosol concentration approaches zero and scattering is principally due to the molecular constituents of the atmosphere. Scattering from such particles is termed Rayleigh scattering after Lord Rayleigh, who in 1871 developed the initial theory for scattering of radiation by air molecules. Rayleigh's law is based upon the assumption that the air molecules are homogenous spherical particles of equal size whose radii are much smaller than the wavelength of the incident electromagnetic radiation. This is clearly the case since atmospheric molecules have dimensions of $10^{-6}$ to $10^{-8}$ microns, much smaller than the 0.25 to 28.5 micron range under study. After these particles are hit by the incident radiation, they become a source of electromagnetic radiation of a specific wavelength transmitted in all directions whose field distribution

is described by Maxwell's equations. Rayleigh's theoretical approach only covers primary scattering and reveals that the scattering coefficient due to air molecules varies inversely with the fourth power of the wavelength (Ref. 5).

## Absorption

Radiation is scattered by all of the atmospheric gaseous molecules, but is selectively absorbed. Minor constituents of the atmosphere such as water vapor, carbon dioxide, ozone, nitrous oxide, carbon monoxide, and methane are dominant factors in the absorption process. The two major atmospheric constituents, nitrogen and oxygen, are minor absorbers when compared to the preceeding list. Atmospheric ozone is particularly effective in absorbing ultraviolet radiation while the infrared is susceptible to water vapor and carbon dioxide. For a detailed explanation of atmospheric absorption see Reference 4.

# III. LOWTRAN5 Computer Code

In order to calculate thermal radiation incident on a target area, the transmissivity of the atmosphere must first be accurately determined. The Fortran computer code, LOWTRAN5, is designed to make this calculation for a given atmospheric path over the frequency range of 0.25 to 28.5 microns on a linear wavenumber scale. A choice of six model atmospheres is given with an option for a seventh model which can be inserted as a set of radiosonde data. Aerosol attenuation is calculated for a given visual range based on an interpolation/extrapolation scheme using any two of eight aerosol models provided.

For horizontal path transmittance calculations under nonstandard conditions, the user can specify meteorological data for use in the program.

## Theory

In determining the transmittance of the atmosphere, LOWTRAN5 follows almost exactly the procedures outlined by McClatchey et al (Ref.13). The main assumptions made are that the atmosphere can be represented by a 33-layer model, and that the average transmittance over a 20 $cm^{-1}$ interval can be represented by a single parameter model of the form

$$T = f(CW). \tag{8}$$

C is a wavelength dependent absorption coefficient and W is an "equivalent absorber amount" for the atmospheric path.

This atmospheric path is defined in terms of the pressure, p(z), temperature, T(z), concentration of absorber, L, and an empirical constant as follows:

$$W = L\left(\frac{P(z)}{P}\sqrt{\frac{T}{T(z)}}\right)^n \qquad (9)$$

If Equation (9) is substituted into Equation (8) and n is set equal to zero and unity, respectively, Equation (8) reverts to the well known weak line and strong line approximations common to most band models (Ref.18).

The form of the function f and parameter n was determined empirically using both laboratory transmittance data and available molecular line constants. In both cases, the transmittance was degraded in resolution to 20 $cm^{-1}$ throughout the entire spectral range.

Model Atmospheres

The altitude, pressure, temperature, water vapor density, and ozone density for the U.S. Standard Atmosphere and five seasonal model atmospheres are provided as basic input data to LOWTRAN5. Also provided are the number of aerosol particles per cubic centimeter for eight haze models. The model atmospheres correspond to the 1962 U.S. Standard Atmosphere, Tropical (15$^{O}$N) Atmosphere, Midlatitude Summer (45$^{O}$N, July), Midlatitude Winter (45$^{O}$N, January), Subarctic Summer (60$^{O}$N, July) and Subarctic Winter (60$^{O}$N, January). The different models are digitized in 1 kilometer steps from 0 to 25 km, 5 km steps from 25 to 50 km, then at 70 km and 100 km directly as given by McClatchey (Ref.17).

The water vapor and ozone altitude profiles added to the 1962 U.S. Standard Atmosphere by McClatchey were obtained from Sissenwine (Ref.21) and Herring (Ref.10) respectively, and correspond to mean annual values. The water vapor densities for the 1962 U.S. Standard Atmosphere correspond to relative humidities of approximately 50 percent for altitudes up to 10 kilometers. However, the relative humidity values for the supplementary models tend to decrease with altitude from approximately 80 percent at sea level to 30 percent at 10 kilometer altitude.

In addition to the model atmospheres provided, the user has the option of inserting his own model atmosphere, or of building another model by combining various parts of the six standard models (Ref.18).

## Atmospheric Constituents

Atmospheric Gases. LOWTRAN5 assumes that mixing ratios of the gases, carbon dioxide, nitrous oxide, methane, carbon monoxide, nitrogen, and oxygen remain constant at all altitudes at the values listed in Table II. These gases as a whole, with the exception of nitrogen, are referred to as the uniformly mixed gases.

Absorption coefficients for water vapor, ozone, and the combined effects of the uniformly mixed gases were digitalized from spectral curves by McClatchey and are included as data for LOWTRAN 5 (Ref.13).

Table II

Mixing Ratios for Atmospheric Gases in Parts per Million

| | |
|---|---|
| CARBON DIOXIDE | 330 |
| NITROUS OXIDE | 0.28 |
| METHANE | 1.6 |
| CARBON MONOXIDE | 0.075 |
| NITROGEN | $7.905 \times 10^{5}$ |
| OXYGEN | $2.095 \times 10^{5}$ |

Continuum Absorption. Absorption coefficients for the water vapor continuum are based on measurements of Burch (Ref. 3), McCoy and Rensch (Ref.14), and Bignell (Ref. 1).

The continuum due to collision induced absorption by nitrogen is included based on the measurements of Reddy and Cho (Ref.16) and Shapiro and Gush (Ref.20).

In all cases the transmittance due to continuum absorption is assumed to follow a simple attenuation law.

Molecular Scattering. The absorption coefficient due to molecular scattering in introduced into LOWTRAN5 via the following expression:

$$M.S. = (9.807\times10^{-20})\ (W^{4.0117})\ \text{km}^{-1} \qquad (10)$$

where W is in wavenumbers ($\text{cm}^{-1}$).

The above expression was obtained as a best fit to molecular scattering coefficients published by Penndorf (Ref.15).

Aerosol Models. Eight aerosol models are incorporated into LOWTRAN5. These include Rural (23km visibility), Rural (5km visibility), Maritime (23km), Maritime (5km), Urban (5km), Tropospheric (50km), Fog1 (0.2km), and Fog2 (0.5km). Although specific visibilities are listed for each model, an aerosol attenuation for any visual range can be calculated using an interpolation/extrapolation procedure.

The Maritime, Urban, Rural, and Average Continental Aerosol Models are all boundary layer models. That is, they apply to the first few kilometers of the atmosphere. The Tropospheric Model was developed primarily for use in the troposphere above the boundary layer. However, it can be used for calculations near ground level for particularly clear and calm conditions in pollution free areas with visibilities greater than thirty to forty kilometers.

The aerosol models are based on the following assumptions. A particle size distribution similar to Deirmendjian's Haze Model C, but where the large particle radius cutoff has been extended to one hundred microns (Ref. 6). The particle size distribution is assumed to remain constant with altitude (Ref.18). The variation of aerosol number density with altitude is assumed to be the same as given by McClatchey for the twenty-three kilometer visual range model. The latter aerosol number densities were adjusted to give extinction coefficients at a wavelength of 0.55 microns that correspond to those obtained by Elterman at each altitude (Ref. 7). The variation

of aerosol refractive index with wavelength has been obtained from measurements by Volz, who found that aerosols are composed of water-soluble substances as well as dust-like material (Ref.25).

Aerosol extinction and aerosol absorption values were calculated based on single scattering Mie theory using the above aerosol size distribution and refractive index values.

The Tropospheric Aerosol Model is the same as the small particle portion of the Rural and Urban models. The larger particles are lost at a higher rate than the small ones, and above the boundary layer they are not replaced by turbulent mixing from the surface. The continental component of the Maritime Model also is the same as the small particle portion of the Rural Model for analgous reasons.

The aerosol models also differ in their composition and the corresponding variation of refractive index with wavelength. The Rural Model is assumed to be a mixture of seventy percent water-soluble aerosols and thirty percent dust-like aerosol.

The Maritime Model is composed of a mixture of aerosols of oceanic and continental origins. The oceanic aerosols are produced primarily by the sea spray and are assumed to be a solution of sea salts in water. The continental component has the same composition as the Rural Model. While the proportions and nature of the two components of the Maritime aerosol will vary geographically, there is insufficient

data to meaningfully model these variations. For simplicity, the oceanic component is taken as contributing seventy-five percent of the extinction at 0.55 microns, which yields a model which is consistent with measurements in a number of different maritime locations (Ref.19).

The Urban Model is similar to the Rural Model, but with an addition of soot-like aerosols such that the mixture is thirty-five percent soot-like aerosols and sixty-five percent rural aerosols. The Tropospheric Model is assumed to have the same composition as the rural aerosols (Ref.19).

The characteristics of the different aerosol models, for the lower atmosphere, are summarized in Table III. The size distributions are represented by one or the sum of two log-normal distributions:

$$\frac{dN(r)}{dr} = \sum_{i=1}^{2} \left(\frac{N_i}{\ell n(10)\, r\sigma_i \sqrt{2\pi}}\right) \exp\left(- \frac{(\log r - \log r_i)^2}{2\sigma_i^2}\right) \qquad (11)$$

The choices of $N_o$ in Table II correspond to one particle per cubic centimeter. The actual size distributions are renormalized to give the correct extinction coefficients and models being used (Ref.19).

Aerosol Interpolation/Extrapolation Scheme. The total extinction coefficient, s(T), at 0.55 microns is inversely proportional to visual range, VIS, and can be written as follows:

$$s(T) = s(a) + s(m) = \frac{3.91}{VIS} \qquad (12)$$

Table III

Characteristics of the Aerosol
Models of the Lower Atmosphere

| AEROSOL MODEL | SIZE DISTRIBUTION | | | | TYPE |
|---|---|---|---|---|---|
| | $i$ | $N_i$ | $r_i$ | $\sigma_i$ | |
| Rural | 1 | 0.9999975 | 0.005 μm | 0.475 | Water-Solubles and |
| | 2 | 0.0000025 | 0.5 μm | 0.475 | Dust-Like |
| Urban | 1 | 0.9999975 | 0.005 μm | 0.475 | Rural Aerosol Mixture and |
| | 2 | 0.0000025 | 0.5 μm | 0.475 | Soot-Like |
| Maritime | | | | | |
| Continental Origin | | 1.0 | 0.005 μm | 0.475 | Rural Aerosol Mixture |
| Marine Origin | | 1.0 | 0.3 μm | 0.4 | Sea Salt Solution in Water |
| Tropospheric | | 1.0 | 0.005 μm | 0.475 | Rural Aerosol Mixture |

This assumes a two percent contrast threshold where the "a" and "m" refer to the aerosol and molecular components respectively. The aerosol extinction coefficient can then be written as:

$$s(a) = \frac{3.91}{VIS} - s(m) \tag{13}$$

Since the aerosol extinction coefficient s(a) is directly proportional to the aerosol number density N(z), it can be written

$$N(Z) = \frac{a(Z)}{VIS} + b(Z) \tag{14}$$

where a(Z) and b(Z) are constants for a given altitude Z. It will be noted that b(Z) is proportional to the molecular scattering coefficient at 0.55 microns at altitude Z, where a molecular absorption has been assumed negligible at $\lambda = 0.55$.

The above equation forms the basis for the interpolation/ extrapolation procedure used in LOWTRAN5 to determine the aerosol attenuation at any given visual range.

The coefficients a and b are determined from the above equation at each altitude using the two aerosol models, that is,

$$a(Z) = (N_5(Z) - N_{23}(Z)) \; / \; (1/5 - 1/23) \tag{15}$$

$$b(Z) = (N_{23}(Z)/5 - N_5(Z)/23) \; / \; (1/5 - 1/23) \tag{16}$$

where $N_5$ and $N_{23}$ refer to the number densities for the five kilometer and twenty-three kilometer visual ranges. The above procedure is used only in the lower five kilometers of the atmosphere since the two aerosol models are identical above five kilometer altitude (Ref.19).

## IV. Computer Model for Thermal Fluence Calculations

Because of the difficulties involved in what is essentially a three-dimensional transport problem, certain simplifying assumptions had to be made in order to produce a fast-running thermal fluence code. LOWTHRM, in its final form, is the result of several preceeding "generations" of the original computer model. As different ideas were incorporated or discarded, the code changed from basically an atmospheric transmittance model to an efficient thermal fluence code. This chapter introduces the thermal source and geometrical models used in the program along with the development of the normalized scatter integral.

### Thermal Pulse

As stated earlier in this report, the nuclear detonation is assumed to be an isotropic, spherical point source at the burst location. Since fluence calculations will be for distances relatively far from the burst point, this approximation should yield reasonable results (Ref. 24). A $6000^{\circ}$K blackbody is generally used to approximate a nuclear airburst. For low altitudes this blackbody is not a bad approximation. As the burst altitude is increased, however, the spectrum shifts toward the ultraviolet wavelengths. To compensate for this shift, an interpolation routine was developed by Johnson (Ref. 2) to raise the blackbody temperature as burst height is

increased. The 6000°K blackbody is used for all burst heights 15 km or less. A 7000°K blackbody is the model for a burst at 25 km. For bursts between 15 and 25 km, linear interpolation is used from the 6000°K energy distribution to the 7000°K energy distribution. For burst heights greater than 25 km, linear interpolation is used from a 7000°K distribution at 25 km to an 8000°K distribution at 35 km. Above 35 km, the 8000°K distribution is used. To increase the flexibility of LOWTHRM, this routine was adopted as a default option. The user may either specify the blackbody temperature under consideration or defer to the computed default value.

The thermal yield of each device under consideration is determined through use of an empirical two-dimensional linear interpolation routine. The routine was developed by the Analysis Division, Air Force Weapons Laboratory (AFWL), Kirtland AFB, New Mexico. It is based on the latest Sputter data with thermal efficiency calculated as a function of height of burst and thermal yield as a function of total weapon yield. The thermal efficiency, T, is given by

$$\begin{aligned} T = \exp\ &((-.358 - .009H + 7.14 \times 10^{-4}H^2) \times 2.30) \times \\ &\exp\ ((-1.25 \times 10^{-5}H^3 + 6.42 \times 10^{-8}H^4) \times 2.30) \end{aligned} \tag{17}$$

where H is the height of burst in kilometers. The thermal yield is then expressed by the relation

$$Y = (T \times W) \times 10^{12} \quad \text{(cal)} \tag{18}$$

where Y is the thermal yield, T is the thermal efficiency,

and W is the total weapon yield in kilotons. Because of the atmospheric model limitations, the altitudes used in the routine should be limited to 100 kilometers. The yield input has a recommended upper limit of 100 megatons (Ref. 12:28).

Direct Fluence Model

Models by Johnson and others had used discrete energy bands to divide the spectrum under consideration. From these bands, average transmittance values were determined and then used across the entire band. From transmittance studies made while examining the basic LOWTRAN5 code, it was found that this broad band approximation was unnecessary. The basic code provided transmissivity data from 350 $cm^{-1}$ to 40000 $cm^{-1}$ (0.25 - 28.5 microns) at 20 $cm^{-1}$ frequency increments. This fine band structure was retained and improves the accuracy of the code.

Computed transmissivity at each frequency interval is weighted with a Planckian spectrum based on the source temperature which is input by the user or computed by Johnson's interpolation routine. The LOWTHRM code begins calculations at 350 $cm^{-1}$ (28.5 microns) and increments in 20 $cm^{-1}$ steps to 40000 $cm^{-1}$ (0.25 microns). To initialize the first weighting factor to 28.5 microns, a routine was incorporated to generate a Planckian integral to this frequency before transmittance calculations were begun. This integral was approximated by a trapezoidal sum of the form:

$$B(350) = \frac{15}{\pi^4} \sum_{u=5}^{350} \frac{u^3(\Delta u)}{e^u - 1} \qquad (19)$$

where B is the value of the integral sum at 28.5 microns, $u = \frac{h\nu}{KT}$, h = Planck's constant ($6.6756 \times 10^{-27}$ erg - sec), $\nu$ = frequency ($\sec^{-1}$), K = Boltzmann's constant ($1.38054 \times 10^{-16}$ erg/$^{O}$K), T = source temperature ($^{O}$K), and $\Delta u = \frac{5h}{KT}$. As the fluence is computed for each frequency interval throughout the range of the program, this integral is continually updated so that the weight for each increment is correct for the source temperature in use. The weight for each band is then:

$$BW(\nu) = B(\nu) - B(\nu - \Delta\nu) \qquad (20)$$

Adding conversion factors to convert kilometers to centimeters and kilotons to calories produces output fluences in units of calories per square centimeter. The direct fluence at frequency $\nu$ can then be approximated by:

$$Q(\nu) = \frac{(BW(\nu))\ (Y)\ (T(\nu))\ (10^{12})}{(4\pi)\ (r \times 10^5)^2} \quad (cal/cm^2) \qquad (21)$$

where Q is the direct fluence at frequency $\nu$, BW is the band weight, Y is the thermal yield, T is the transmittance, and r is the path length (km). The sum over all wavelengths is the total direct fluence on target and is approximated by

$$Q_t = \sum_{\nu=350}^{40000} Q(\nu) \qquad (cal/cm^2) \qquad (22)$$

where $\nu$ is incremented in 20 $cm^{-1}$ steps.

## Scattered Fluence Model

Research revealed two possible models to approximate scattered fluence. The Air Force Weapons Laboratory (AFWL) TRAP Code (Ref. 11) uses an empirical buildup factor to account for diffuse scattering by the atmosphere. To use this buildup factor, scattering coefficients based on height and wavelength had to be computed for each frequency interval. LOWTHRM was modified to use this buildup factor and results were compared with published values. The computed scattered fluences were much lower than expected and the buildup factor model was not retained in LOWTHRM.

Tedesco (Ref. 24) developed a single-scatter integral for use as a computer model in thermal fluence calculations. This model assumes that any radiation which is scattered more than once along its path will not be incident upon the receiver in the time interval under consideration. Due to the long mean free paths of thermal radiation in air, this assumption is a reasonable approximation. A further assumption is that the transmission medium is undisturbed by the nuclear radiation flux from the detonation. A close examination of his work revealed that his basic transmission model closely parallelled the 1962 U.S. Standard Atmosphere and Rural Aerosol Model options available in LOWTHRM. A telephone conversation with Mr. Frank Kneizys of the Air Force Geophysics Laboratory (AFGL), Hanscom AFB, Massachusetts verified that all necessary values for scattering coefficients and absorber amounts were available

through the LOWTRAN5 code. The single-scatter integral was incorporated into LOWTHRM. Because the model now required double integrations over all scattering planes and frequencies, execution time was a major problem. Tedesco had complained of this even over the fourteen bands that his model used. The complication was much worse in LOWTHRM since there are approximately two thousand increments in the range of the program. Results close to those published by Tedesco could be obtained, but run times were well in excess of four hundred seconds execution time. The range of LOWTHRM was reduced to 0.25 to 4.0 microns; making the assumption that very little of the spectrum was beyond this wavelength. This change did produce minor reductions in the direct fluences. However, the execution time was still in the 100 to 300 second range depending upon the particular problem and number of scattering levels involved.

This execution time problem is resolved in LOWTHRM by modifications to the scatter integral. Tedesco had used a fifth degree, least square polynomial curve fit to approximate Mie and Rayleigh scattering. Curve fit coefficients varied as the frequency increased throughout the range of his program (Ref. 24:84). This curve fit was discarded and is replaced in LOWTHRM by simple isotropic scatter. The single-scatter integral was rewritten in terms of angular integrations only and then normalized to the direct fluence. By normalizing to the direct fluence, the scatter integral

produces a ratio which is independent of frequency. By multiplying this ratio times the direct fluence at any wavelength, the scattered amount for that wavelength is then obtained. Thus, the requirement for scatter integrations at each frequency increment is eliminated and greatly reduces execution time. The ratio is developed in the following manner.

The scatter geometry is shown in Figure 2. Distances have been normalized to the vertical displacement of the burst point from the scattering plane. The outward unit surface normal of the receiver has components $X_n$, $Y_n$, and $Z_n$. $X_n$ is in the horizontal plane parallel to the scattering plane and is positive toward the burst point. $Y_n$ is in the horizontal plane and normal to $X_n$, and, due to symmetry, may be considered positive in any direction. $Z_n$ is normal to the scattering plane and is positive toward the scattering plane.

The elemental area dA (normalized to burst height squared) is

$$dA = \tan\theta \sec^2\theta d\theta d\phi \tag{23}$$

The radiation normally incident at the elemental area dA is $T_2 q \cos^3\theta/4\pi$. Parameter q is the total radiant energy intensity from the source and $T_2$ is the transmittance from the burst to dA. The fraction of this radiation scattered to the receiver point is $T_3 \cos^2\beta/4\pi H^2$ where $T_3$ is the transmittance from dA to the receiver. The direct radiation at the receiver point is $qT_1/4\pi((H-1)^2 + G^2)$. The ratio of the scattered radiation to the direct is then:

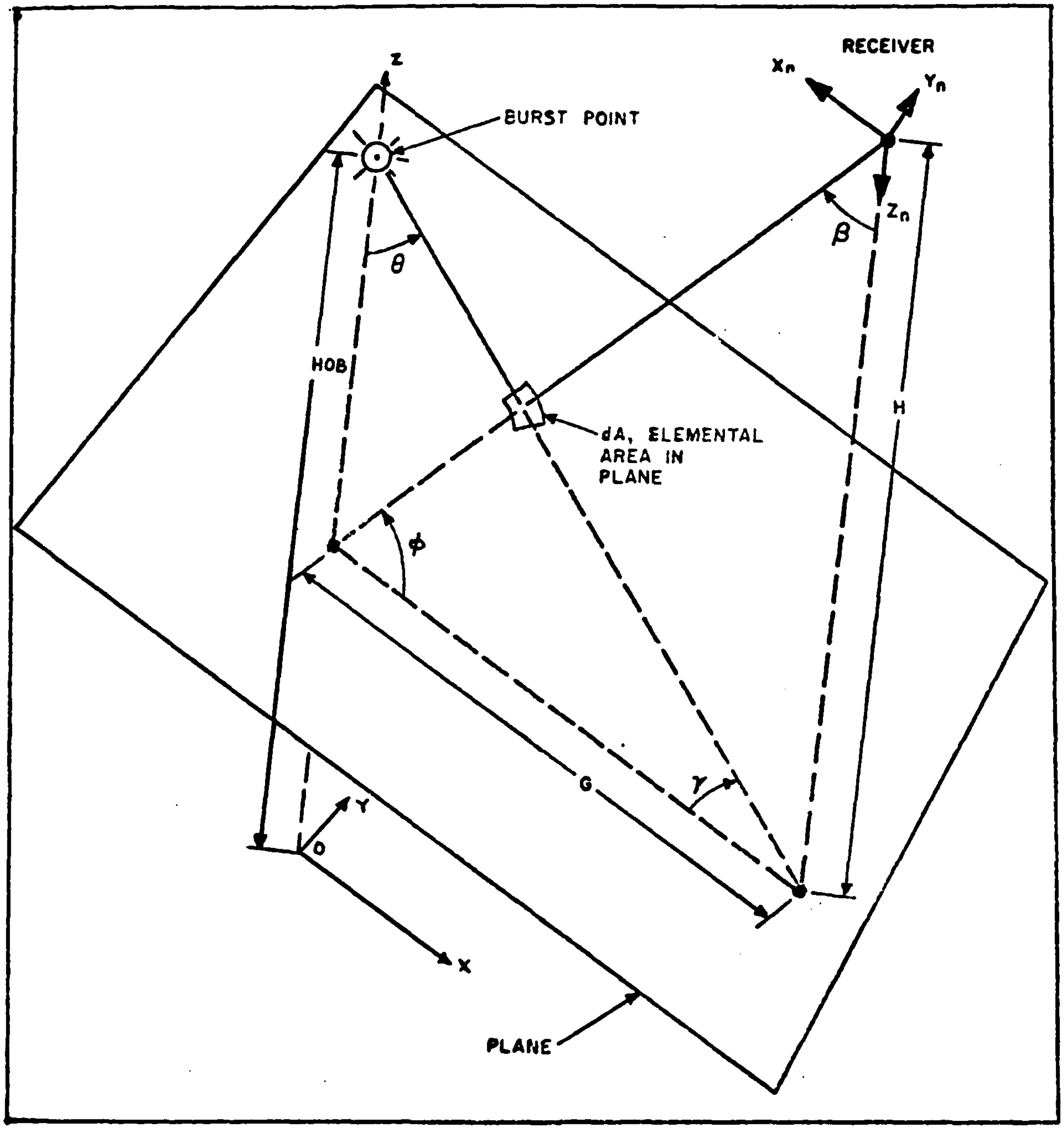


Fig. 2. Scatter Geometry (Ref. 11:49)

$$\frac{\text{scattered}}{\text{direct}} = \frac{4\pi((H-1)^2+G^2)}{qT_1}\int_\theta \int_\phi \frac{T_2 q\cos^3\theta T_3\cos^2\beta\tan\theta\sec^2\theta d\theta d\phi}{(4\pi)(4\pi H^2)} \tag{24}$$

$$\frac{\text{scattered}}{\text{direct}} = \frac{T_2T_3((H-1)^2+G^2)}{T_1 4\pi}\int_\theta \int_\phi \frac{\cos^3\theta\cos^2\beta\tan\theta\sec^2\theta d\theta d\phi}{H^2} \tag{25}$$

$$\frac{\text{scattered}}{\text{direct}} = \frac{T_2T_3((H-1)^2+G^2)}{T_1 4\pi}\int_\theta \int_\phi \frac{\cos^2\beta\sin\theta d\theta d\phi}{H^2} \tag{26}$$

The component of scattered radiation normal to the receiver must now be determined. The unit surface normal may be written in vector form as $X_n\bar{i} + Y_n\bar{j} + Z_n\bar{k}$. A unit vector from the receiver to the area dA is:

$$(H\tan\beta\cos\gamma i + H\tan\beta\sin\gamma j + Hk)\cos\beta/H$$

The dot product of these two vectors is the cosine of the angle between the surface normal and the ray from the area dA. Multiplying the integrand of Equation (26) by this dot product then yields the component of the scattered radiation normal to the receiver. So, the ratio of the scattered to the direct may be written as:

$$\text{RATIO} = \frac{T_2T_3((H-1)^2+G^2)}{T_1 4\pi} \times$$

$$\int_\theta \int_\phi \frac{\cos^3\beta\sin\theta(X_n\tan\beta\cos\gamma+Y_n\tan\beta\sin\gamma+Z_n)d\theta d\phi}{H^2} \tag{27}$$

Before the integration can be performed, $\beta$ and $\gamma$ must be expressed in terms of $\theta$ and $\phi$. Referring again to Figure 2.

$$H\tan\beta\cos\gamma + \tan\theta\cos\phi = G \tag{28}$$

$$\tan\beta\cos\gamma = \frac{G - \tan\theta\cos\phi}{H} \tag{29}$$

$$H\tan\beta\sin\gamma = \tan\theta\sin\phi \tag{30}$$

$$\tan\beta\sin\gamma = \frac{\tan\theta\sin\phi}{H} \tag{31}$$

$$\cos\beta = \frac{H}{(H^2+G^2+\tan^2\theta-2G\tan\theta\cos\phi)^{\frac{1}{2}}} \tag{32}$$

Substituting the above equations into Equation 5,

$$\text{RATIO} = \frac{T_2T_3((H-1)^2+G^2)}{T_1 4\pi} \int_\theta \int_\phi \frac{H^3\sin\theta}{(H^2+G^2+\tan^2\theta-2G\tan\theta\cos\phi)^{3/2}} \tag{33}$$

Collecting terms we have,

$$\text{RATIO} = \frac{T_2T_3((H-1)^2+G^2)H}{T_1 4\pi} \times$$

$$\int_\theta \int_\phi \frac{\sin\theta(X_n(G-\tan\theta\cos\phi)+Y_n(\tan\theta\sin\phi)+Z_nH)\,d\theta d\phi}{(H^2+G^2+\tan^2\theta-2G\tan\theta\cos\phi)^{3/2}} \tag{34}$$

All values are known except for $T_2$ and $T_3$. These are approximated by the expression:

$$\int_o^Z T(Z)\,dZ = \frac{1}{N}\sum_{i=1}^{N} T(Z)\Delta Z \tag{35}$$

where $\Delta Z$ is taken as 1 kilometer for ease of calculation and N is the distance from the source to the scattering plane for $T_2$ and the distance from scattering plane to the receiver for $T_3$. Values for transmittance at altitude Z, T(Z), were determined from the LOWTRAN5 code for each model atmosphere by taking average transmittances for each one kilometer layer of the atmosphere up to a height of one hundred kilometers.

This was accomplished for both the 23 km and the 5 km visibility profiles. Transmittances to two hundred kilometers were approximated as equal to the one hundred kilometer value. These values were stored in data arrays for use in subsequent scattering calculations when called by the sort routine.

The sort routine determines the number of scattering planes for each particular problem. Three special cases are considered and depicted in Figure 3. In case one the number of scattering planes is limited to twice the number of kilometers in the path length, i.e. 20 planes for a 10 km path. In this case the burst height is exactly equal to the path length. Case two considers path lengths greater than burst altitude. In this case the number of scattering planes is limited to the number of kilometers in the path length plus the burst height, i.e. 17 for a path length of 10 km and burst height of 7 km. The final case is for burst height greater than path length. Scattering plane determination is the same as for case two, i.e. 17 for a 10 km burst and 7 km path length. The use of the path length to limit the number of scattering planes is based on studies of the scattering ratio. Contributions to scatter rapidly decrease as the distance from burst to scatter plane increases. The scattering ratio for planes at distances greater than the path length produced values that were about one per cent of the contributions from planes close to the burst. Because these contributions are so small, the sort routine limits the number of planes as described in this paragraph.

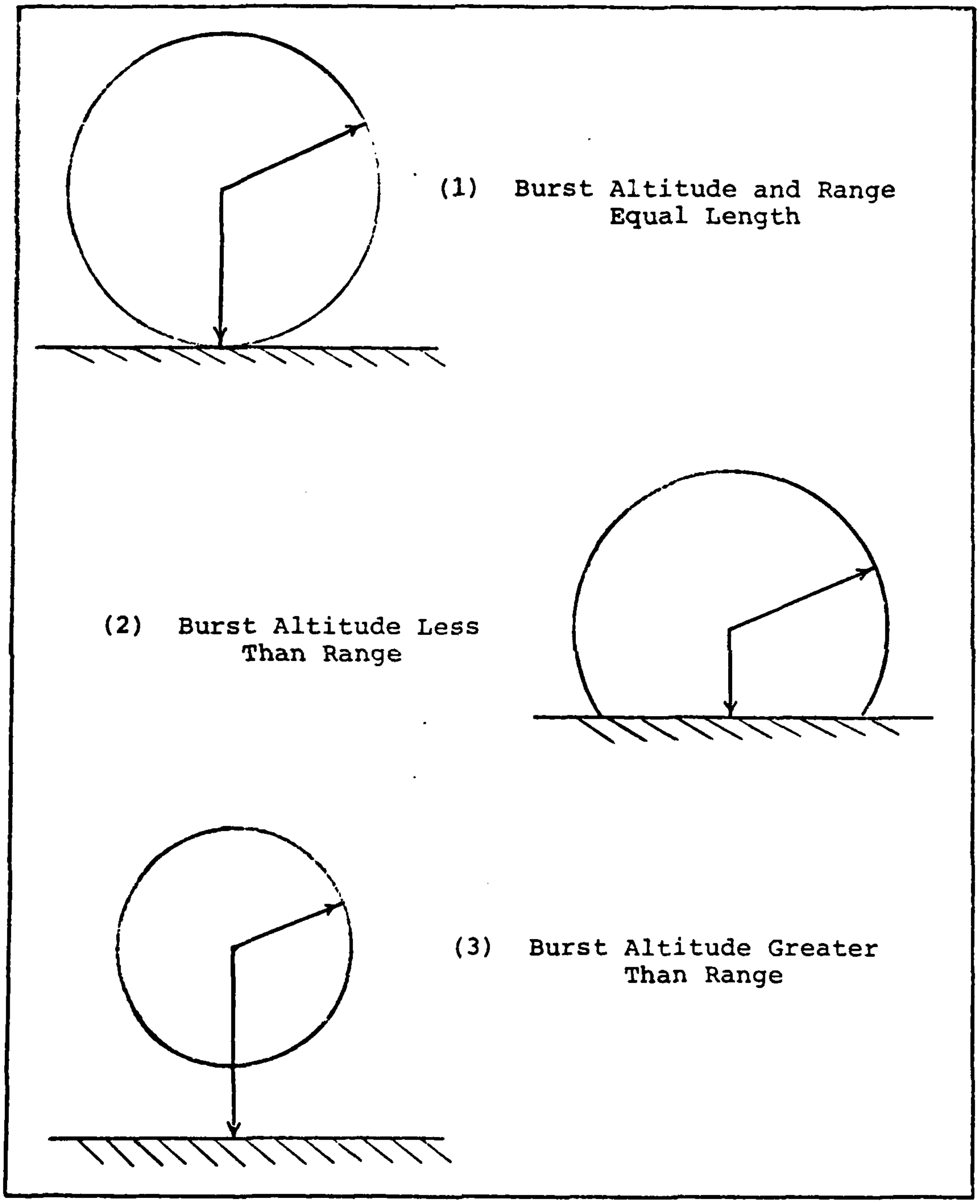


Figure 3. Burst Geometries

To actually perform the required angular integrations, a subroutine used in the AFWL Trap Code (Ref. 11) was modified for use in LOWTHRM. Integrations over each scattering plane are performed as called by the sort routine. As the direct fluence at each wavelength is determined and summed, the scattered fluence is calculated and added to its sum. The approximation is:

$$Q_s = (\mathrm{RATIO}) \sum_{\nu=350}^{40000} Q(\nu) \tag{36}$$

where $Q_s$ is the total scattered fluence, RATIO is the computed ratio of scattered to direct fluence, $Q(\nu)$ is the direct fluence at frequency $\nu$, and $\nu$ is incremented in 20 $cm^{-1}$ steps.

Ground Reflection Model

In order to be a complete fluence model, LOWTHRM includes a ground reflected contribution with variable surface albedo. The albedo values along with corresponding reflecting surfaces are listed in Table IV (Ref. 4). The ground reflected fluence was treated similarly to the scattered fluence in that a normalized reflection integral was developed. The problem is simplified somewhat since there is only one plane required for ground reflection instead of the several required for scatter computations. One additional assumption is that the ground reflectance can be approximated by Lambert's cosine law. This results in an additional factor of $2\cos\beta$ in the numerator of Equation (24). The integral is developed in

the same manner as the scatter integral and will not be repeated here. Adding the variable albedo constant, the final reflection integral is:

$$RR = \frac{T_4 T_5 \varepsilon H((H-1)^2+G^2)}{T_1 \pi} \times \tag{37}$$

$$\int_\theta \int_\phi \frac{\sin\theta(X_n(G-\tan\theta\cos\phi)+Y_n\tan\theta\sin\phi+Z_n H)\,d\theta d\phi}{(H^2+G^2+\tan^2\theta-2G\tan\theta\cos\phi)^2}$$

where RR is the reflection ratio of the reflected to the direct fluence, $T_4$ is the transmittance from the ground to the receiver, $T_5$ is the transmittance from the burst to the receiver, and $\varepsilon$ is the albedo constant. Angles $\theta$ and $\phi$ and variables G and H are specified in Figure 4. As in the scatter approximation, all values of the reflection integral are known except $T_4$ and $T_5$. These are approximated by the expression:

$$\int_0^Z T(Z)\,dZ = \frac{1}{N}\sum_{i=1}^{N} T(Z)\Delta Z \tag{38}$$

where $\Delta Z$ is 1 km, T(Z) is the average transmittance at altitude Z, and N is the distance from the source to the ground for $T_4$ and the distance from the ground to the receiver for $T_5$.

With the completion of the ground reflected component, the model has been completely specified. The only possible addition would be to include a variable cloud albedo and scattering approximations within cloud layers. Since no

Table IV

Variable Surface Albedos

| SURFACE | ALBEDO |
|---|---|
| Desert | 0.310 |
| Various Fields | 0.190 |
| Green Forest | 0.115 |
| Grass | 0.305 |
| Bare Ground | 0.185 |
| Dry Sand | 0.230 |
| Wet Sand | 0.140 |
| Snow or Ice | 0.680 |
| Rough Water | 0.205 |
| Average Water | 0.100 |
| Shock-Frothed Water | 0.600 |

literature could be found to approximate these effects, cloud layers were omitted in the thermal scatter calculations.

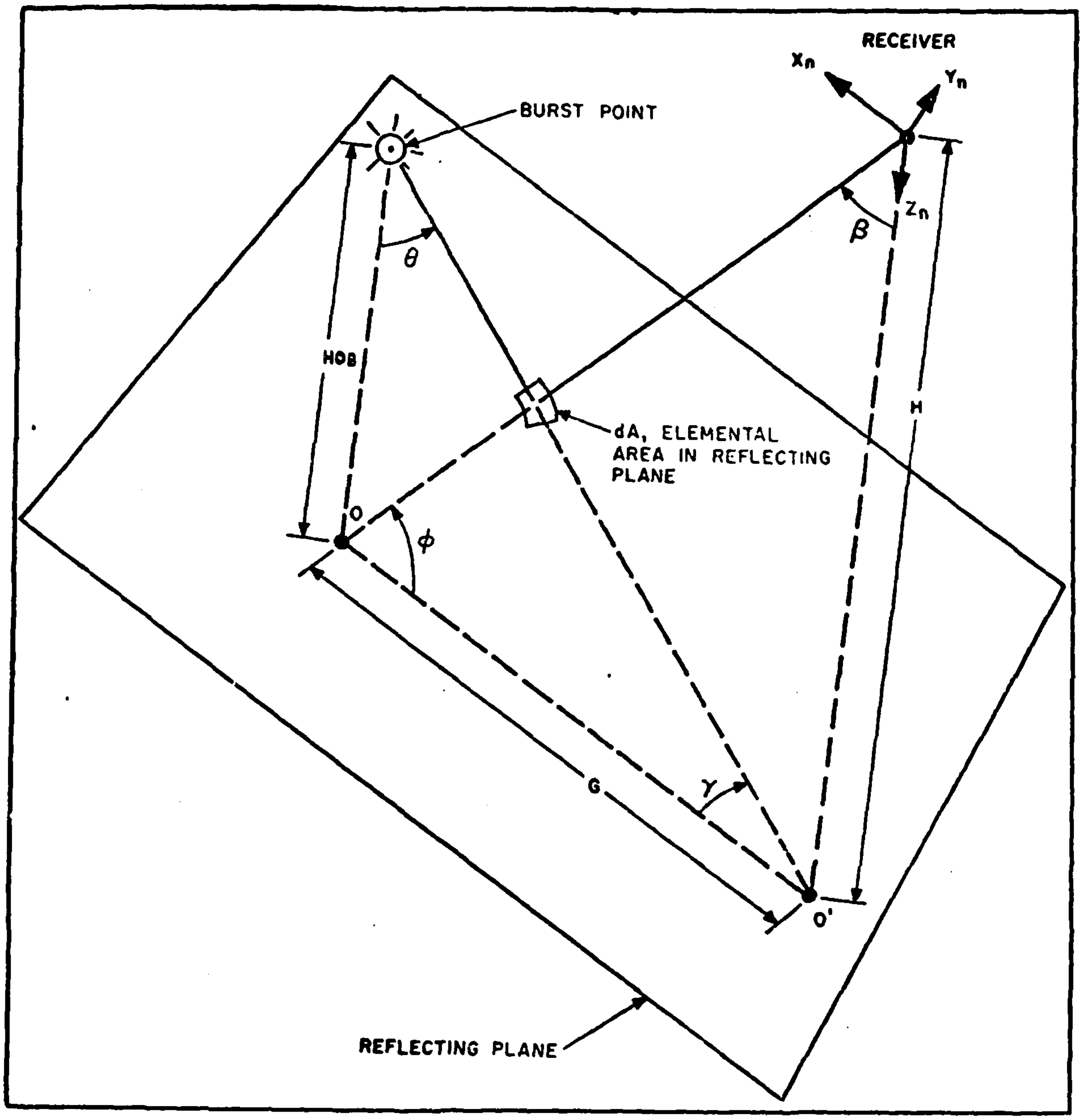


Fig. 4. Reflection Geometry (Ref. 11:49)

## V. Results and Conclusions

As mentioned in the introduction, the purpose of this thesis is to incorporate atmospheric transmissivity factors into a new thermal radiation code. To determine the validity of this model, results are compared against Tedesco's Single-Scatter model, (Ref.24) the AFWL Snare code (Ref.11), Johnson's Virgin Fluence model (Ref.12), and the Thermal Routine from Horizon Technology, Inc. which has been developed for use on the Texas Instruments TI-59 calculator (Ref. 8). Table V shows a comparison for LOWTHRM against Tedesco's Single-Scatter model and the AFWL Snare code. All fluences are for horizontal paths at the altitudes indicated. The LOWTHERM model atmosphere used was the 1962 U.S. Standard Atmosphere with the Rural (23km) Aerosol Model. Since Tedesco used a ground reflection albedo of 0.35, LOWTHRM was modified to accept that value for comparative purposes. A comparison of the values listed in Table V shows strong agreement up to an altitude of twenty-five kilometers. For the runs at twenty-five and thirty-five kilometers, LOWTHRM yields higher fluences on target. This may be due to the better transmission calculations LOWTHRM offers, a difference in the spectrum used to weight each frequency interval, or a combination of both. The results for two available runs of the AFWL Snare code are listed for comparative purposes of current Air Force estimates of thermal fluence. It should be noted that these

estimates are based upon a visibility of ten miles at sea level, while LOWTHRM is based upon the more accurate parameter of meteorological range.

Table V

Fluence Comparison for LOWTHRM, Single-Scatter Model, and AFWL Snare Codes

| HEIGHT (km) | PATH (km) | YIELD (kt) | LOWTHRM ($cal/cm^2$) | SINGLE-SCATTER ($cal/cm^2$) | SNARE ($cal/cm^2$) |
|---|---|---|---|---|---|
| 2 | 10 | 1000 | 25.17 | 25.49 | 28.5 |
| 5 | 10 | 1000 | 35.41 | 35.77 | - |
| 7 | 10 | 1000 | 35.99 | 36.18 | 36.5 |
| 15 | 8 | 100 | 5.34 | 5.41 | - |
| 25 | 8 | 100 | 5.69 | 4.79 | - |
| 35 | 16 | 1000 | 15.85 | 13.09 | - |

Table VI is a comparison between Johnson's Virgin Fluence model, LOWTHRM, and the Thermal Routine from the Nuclear Weapons Effects Programs Weapons Manual.

Table VI

Fluence Comparison for Virgin Fluence Model, LOWTHRM, and HTI Thermal Routine

| TARGET (km) | BURST (km) | RANGE (km) | YIELD (kt) | VIRGIN ($cal/cm^2$) | LOWTHERM ($cal/cm^2$) | THERMAL ($cal/cm^2$) |
|---|---|---|---|---|---|---|
| 0 | 2 | 5 | 200 | 13.21 | 18.32 | 19.26 |
| 0 | 5 | 10 | 200 | 3.04 | 6.03 | 4.53 |
| 0 | 10 | 12 | 1000 | 12.20 | 25.82 | 17.23 |

It should be noted that Johnson's Virgin Fluence Model is for direct fluence values only. The values listed in Table VI differed from LOWTHRM direct fluences only by seven to ten percent. The Thermal Routine by Horizon Technology, Inc. appears to be a "data fit" of some sort which yields fluences fairly close to LOWTHRM and the other models investigated in this report.

In conclusion, LOWTHRM is a fast running code that can calculate thermal fluence for a variety of model atmospheres and aerosol conditions. The "exact" atmospheric transmissivity factors used in the direct fluence calculations provide the basis for a high degree of accuracy while the adoption of the normalized scatter integral greatly reduces execution times with no loss in output fluences.

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# Appendix A

## LOWTHRM User's Guide

LOWTHRM is activated by submission of one data card. The data card is read in a free field format of the form

```
READ*,MODEL,IHAZE,ITYPE,ISEASN,VIS,W1A,T1A,IPOSIT,IABEDO,
  H1,H2,RANGE
```

Parameter one, MODEL, is used to specify one of the following atmospheres by entering an integer value between 0 and 7.

0 = Horizontal path and meteorological data are user specified

1 = Tropical Atmosphere

2 = Midlatitude Summer

3 = Midlatitude Winter

4 = Subarctic Summer

5 = Subarctic Winter

6 = 1962 U.S. Standard Atmosphere

7 = New Model is user specified using radiosonde data

IHAZE is an integer value entered to select the appropriate aerosol mode.

1 = Rural (23km)

2 = Rural (5km)

3 = Maritime (23km)

4 = Maritime (5km)

5 = Urban (5km)

6 = Tropospheric (50km)

7 = User Defined

8 = Fog1 (0.2km)

9 = Fog2 (0.5km)

Parameter three, ITYPE, is an integer used to indicate the type of atmospheric path.

1 = Horizontal path

2 = Vertical or slant path between two altitudes

ISEASN specifies seasonal visibility profiles.

1 = Spring-Summer

2 = Fall-Winter

Parameter five is VIS. This is a real value which specifies the visual range (km) at sea level. Any value other than zero will activate the interpolation/extrapolation routine contained in LOWTHRM. If VIS is set equal to zero, a default value is assigned equal to the visibility specified by IHAZE.

W1A is a real value which is the weapon yield in kilotons.

T1A is the temperature ($^{o}$K) of the Planckian spectrum used to weight the transmission calculations. If the user sets T1A equal to zero, LOWTHRM computes a default value based on the height of burst. T1A is entered as a real value.

Parameter eight is IPOSIT. It is used to specify the receiver orientation and is entered as a single integer value.

IPOSIT specifies the direction cosines of the unit vector normal to the target surface. Values of X are positive in the direction of the burst. Values of Z are positive towards the ground. If direction cosines other than those listed below are required, the user can select his own values by setting IPOSIT equal to 0 and then entering the desired values, i.e.---,T1A,0,.866,.866,.866,IALBEDO,H1,H2,RANGE.

| | X | Y | Z |
|---|---|---|---|
| 1 = | 1. | 0. | 0. |
| 2 = | .866 | 0. | -.5 |
| 3 = | .5 | 0. | -.866 |
| 4 = | -.5 | 0. | -.866 |
| 5 = | -.866 | 0. | -.5 |
| 6 = | -1. | 0. | 0. |
| 7 = | -.866 | 0. | .5 |
| 8 = | -.5 | 0. | .866 |
| 9 = | 0. | 0. | 1. |
| 10 = | .5 | 0. | .866 |
| 11 = | .866 | 0. | .5 |
| 12 = | .866 | .5 | 0. |
| 13 = | .5 | .866 | 0. |
| 14 = | 0. | 1. | 0. |
| 15 = | -.5 | .866 | 0. |
| 16 = | -.866 | .5 | 0. |
| 17 = | 0. | .5 | -.866 |
| 18 = | 0. | .866 | -.5 |
| 19 = | 0. | .866 | .5 |
| 20 = | 0. | .5 | .866 |

Parameter nine is IALBEDO. This is an integer value used to select the ground reflection constant. The user can select his own ground reflection constant by setting IALBEDO to 0

followed by the desired constant, i.e.---IPOSIT,0,.725,H1,---.

1 = Desert (0.310)
2 = Various Fields (0.190)
3 = Green Forest (.115)
4 = Grass (0.305)
5 = Bare Ground (0.185)
6 = Dry Sand (0.280)
7 = Wet Sand (0.140)
8 = Snow or Ice (0.680)
9 = Rough Water (0.205)
10 = Average Water (0.100)
11 = Shock-Frothed Water (0.600)

Parameter ten is H1. This is a real value which corresponds to the target altitude in kilometers.

H2 is the burst attitude in kilometers.

The final parameter is RANGE. This specifies the slant range between the burst and receiver. It is a real value with units of kilometers.

To facilitate use of LOWTHRM, it is recommended that the binary source deck be stored on a permanent file, LWTHERM, cycle one. The data deck should be stored on permanent file, LWTHERM, cycle two. The program may then be attached and run as follows:

```
xxx,T30,CM100000,STANY.
ATTACH,WES,LWTHERM,CY=1
ATTACH,TAPE5,LWTHERM,CY=2
WES.
7/8/9
DATA CARD
7/8/9
6/7/8/9
```

The above procedure eliminates the need to read the source program and data deck for each run.

There are two special cases which may be of interest to some users. Case one is for a horizontal path when meteorological data is used. In this instance, MODEL is set to zero. After the data card, enter a second card with the following information:

H1 (km), pressure (mb), temperature (degrees C), dew point temperature (deg. C), percent relative humidity, water vapor density (gm/m$^3$), ozone density (gm/m$^3$), RANGE (km).

When using this option, Format statement 429 in Subroutine NSMDL specifies the input to be used for the above.

Case two allows the user to build a new model atmosphere. On the data card set MODEL to seven and add data cards for each altitude level in the new model atmosphere. Each new card should contain the following:

altitude (km), pressure (mb), temperature (Deg. C), Dew point (Deg. C), relative humidity, water vapor density (gm/m$^3$), ozone density (gm/m$^3$), aerosol number density (cm$^{-3}$), VIS, IHAZE, ISEASN, and IVULCN.

Format 435 from Subroutine NSMDL is used for case two.

Other parameters within LOWTHRM which may be varied by the user include M1, M2, M3, RO, TBOUND, IVULCN, ANGLE, BETA, IM, ML, LEN, and Y. With the exception of Y, these parameters are normally set equal to zero for operation of the program, but may be varied by the user. To change them, a card substitution is required in the source program for each parameter that is to be changed. This means the user must

remove the card that states M1=0 and replace it with the option chosen, i.e. M1=1. Each parameter is annotated with comment cards in the listing so that each is easy to find and substitution is simple when required.

M1 is an integer used to vary temperature altitude profiles.

0 = Normal Operation

1 = Tropical

2 = Midlatitude Summer

3 = Midlatitude Winter

4 = Subarctic Summer

5 = Subarctic Winter

6 = 1962 U.S. Standard

M2 is an integer used to vary water vapor altitude profiles.

0 = Normal operation

1 = Tropical

2 = Midlatitude Summer

3 = Midlatitude Winter

4 = Subarctic Summer

5 = Subarctic Winter

6 = 1962 U.S. Standard

M3 is used to vary ozone altitude profiles.

0 = Normal Operation

1 = Tropical

2 = Midlatitude Summer

3 = Midlatitude Winter

4 = Subarctic Summer

5 = Subarctic Winter

6 = 1962 U.S. Standard

RO is a real value which specifies the radius of the earth at the particular location at which the calculation is to be performed. If RO is set equal to zero, default value is the earth radius for the model atmosphere selected.

TBOUND is the earth temperature in degrees Kelvin. TBOUND equals zero defaults to the air temperature of the model atmosphere selected.

IVULCN is an integer defining the ten to thirty kilometer aerosol visibility profile.

0 = Default to Stratospheric background

1 = Stratospheric background

2 = Aged Volcanic type/Moderate content

3 = Fresh Volcanic type/High content

4 = Aged Volcanic type/High content

5 = Fresh Volcanic type/Moderate content

ANGLE is the zenith angle at H1. If ANGLE is set equal to zero, a default value is computed from values specified for H1, H2, and RANGE.

BETA is the earth center angle subtended by H1 and H2. If BETA is set equal to zero, a default value is computed from values specified for H1, H2, and RANGE.

IM is an integer value for use with MODEL equal to seven. This corresponds to special case two previously mentioned and IM should be set equal to one.

ML is an integer value for the number of atmospheric levels to be read in for special case two. For horizontal paths ML=1. For slant paths ML equals the number of one kilometer levels traversed.

LEN is a path length control parameter. For some calculations in which ANGLE or BETA have been specified, LOWTHRM may determine that there are two possible paths for computations. In this event, a message will indicate the shorter path was computed. To select the longer path, set LEN equal to one.

The last parameter to be discussed is Y, the thermal yield. Some literature specifies methods for computing the thermal yield other than the model used in LOWTHRM. To change the thermal yield approximation, the user may substitute source program cards at the point documented in the program listing.

# Appendix B

## Sample Problems

This appendix contains six sample problems to further aid the user in running LOWTHRM. These problems are not "all inclusive" in exercising the options made available. They do, however, give the potential user output for specific problems and an insight into what can be done with LOWTHRM.

Problem 1

The first sample problem is to compute the total fluence on target for a 200 kiloton weapon with the receiver at 1 kilometer height and the burst at 3 kilometer height. Slant range is 4 kilometers. The 1962 U.S. Standard Atmosphere is used with the Rural Aerosol model. Sea level visibility is 23 kilometers. Ground reflection is from desert and receiver direction cosines are X = 1.0, Y = 0., and Z = 0. The season is spring.

The data card parameters for problem one are:

MODEL = 6
IHAZE = 1
ITYPE = 2
ISEASN = 1
VIS = 0. (Defaults to IHAZE value)
W1A = 200.
T1A = 0. (Defaults to a value based on height of burst)
IPOSIT = 1
IALBEDO = 1
H1 = 1.
H2 = 3.
RANGE = 4.

Since the data card is read in a free field format, it may be punched as:

6,1,2,1,0.,200.,0.,1,1,1.,3.,4.

Output is as follows:

INPUT PARAMETERS...

WEAPON YIELD IS 200. KILOTONS

SLANT PATH BETWEEN ALTITUDES H1 and H2 WHERE H1 = 1.000 KM H2 = 3.000 KM

PATH LENGTH IS 4.00 KM

HAZE MODEL = 23.0 KM VISUAL RANGE AT SEA LEVEL

MODEL ATMOSPHERE 6 = 1962 US STANDARD

HAZE MODEL 1 = RURAL VIS = 23.0KM

SEASON = SPRIG SUMM

GROUND REFLECTION IS FROM DESERT

RECEIVER DIRECTION COSINES ARE X = 1.000 y = 0.000 Z = 0.000

VERTICAL PROFILE AEROSOL MODEL = STRAT BKGR

OUTPUT PARAMETERS...

AT THE SOURCE...

IR THERMAL YIELD IS 40.53 KILOTONS

VISIBLE THERMAL YIELD IS 31.45 KILOTONS

UV THERMAL YIELD IS 10.65 KILOTONS

TOTAL THERMAL YIELD IS 83.70 KILOTONS

AT THE RECEIVER...

IR UNREACTED FLUENCE IS 14.88 CAL/CM2

VISIBLE UNREACTED FLUENCE IS 12.60 CAL/CM2

UV UNREACTED FLUENCF IS 2.79 CAL/CM2

TOTAL UNREACTED FLUENCE IS 30.27 CAL/CM2

SCATTERED FLUENCE IS 5.73 CAL/CM2

REFLECTED FLUENCE IS 2.55 CAL/CM2

TOTAL FLUENCE ON TARGET IS 38.55 CAL/CM2

Problem 2

Problem number two is to repeat problem one but change the receiver direction cosines to X = 0, Y = 0, and Z = 1.

The only parameter different than problem number one is IPOSIT.

IPOSIT = 9

The Data card is now:

6,1,2,1,0.,200.,0.,9,1,1.,3.,4.

The output on the following page reflects the change in receiver orientation:

INPUT PARAMETERS..

WEAPON YIELD IS 200. KILOTONS

SLANT PATH BETWEEN ALTITUDES H1 AND H2 WHERE H1 = 1.000 KM H2 = 3.000 KM

PATH LENGTH IS 4.000 KM

HAZE MODEL = 23.0 KM VISUAL RANGE AT SEA LEVEL

MODEL ATMOSPHERE 6 = 1962 US STANDARD

HAZE MODEL 1 = RURAL VIS = 23.0KM

SEASON = SPRIG SUMM

GROUND REFLECTION IS FROM DESERT

RECEIVER DIRECTION COSINES ARE X= 0.000 Y = 0.000 z = 1.000

VERTICAL PROFILE AEROSOL MODEL = STRAT BKGR

OUTPUT PARAMETERS...

AT THE SOURCE...

IR THERMAL YIELD IS 40.53 KILOTONS

VISIBLE THERMAL YIELD IS 31.45 KILOTONS

UV THERMAL YIELD IS 10.65 KILOTONS

TOTAL THERMAL YIELD IS 83.70 KILOTONS

AT THE RECEIVER...

IR UNREACTED FLUENCE IS 0.00 CAL/CM2

VISIBLE UNREACTED FLUENCE IS 0.00 CAL/CM2

UV UNREACTED FLUENCE IS 0.00 CAL/CM2

TOTAL UNREACTED FLUENCE IS 0.00 CAL/CM2

SCATTERED FLUENCE IS 7.56 CAL/CM2

REFLECTED FLUENCE IS 3.61 CAL/CM2

TOTAL FLUENCE ON TARGET IS 11.16 CAL/CM2

Problem 3

The third example repeats problem one with the receiver at 20 kilometers, the burst at 30 kilometers, and a slant range of 10 kilometers.

H1 = 20.

H2 = 30.

RANGE = 10.

All other parameters are the same as for problem one.

The Data card is now:

6,1,2,1,0.,200.,0,1,1,20.,30.,10.

The output on the following page indicates an increase in thermal yield due to a change in the height of burst and a decrease in fluence due to increased path length.

INPUT PARAMETERS...

WEAPON YIELD IS 200. KILOTONS

SLANT PATH BETWEEN ALTITUDES H1 AND H2 WHERE H1 = 20.000 KM H2 = 30.000 KM

PATH LENGTH IS 10.000 KM

HAZE MODEL = 23.0 KM VISUAL RANGE AT SEA LEVEL

MODEL ATMOSPHERE 6 = 1962 US STANDARD

HAZE MODEL 1 = RURAL VIS = 23.0KM

SEASON = SPRIG SUMM

GROUND REFLECTION IS FROM DESERT

RECEIVER DIRECTION COSINES ARE X = 1.000 Y = 0.000 Z = 0.000

VERTICAL PROFILE AEROSOL MODEL = STRAT BKGR

OUTPUT PARAMETERS...

AT THE SOURCE...

IR THERMAL YIELD IS 36.43 KILOTONS

VISIBLE THERMAL YIELD IS 42.28 KILOTONS

UV THERMAL YIELD IS 24.28 KILOTONS

TOTAL THERMAL YIELD IS 108.26 KILOTONS

AT THE RECEIVER...

IR UNREACTED FLUENCE IS 2.88 CAL/CM2

VISIBLE UNREACTED FLUENCE IS 3.31 CAL/CM2

UV UNREACTED FLUENCE IS 1.27 CAL/CM2

TOTAL UNREACTED FLUENCE IS 7.46 CAL/CM2

SCATTERED FLUENCE IS .16 CAL/CM2

REFLECTED FLUENCE IS .03 CAL/CM2

TOTAL FLUENCE ON TARGET IS 7.65 CAL/CM2

Problem 4

The fourth example problem determines the thermal fluence on target for a 1 megaton weapon with the target and burst co-altitude at 7 kilometers. The path length is 10 kilometers. The model is Tropical with the Rural Aerosol Model. Sea level visibility is 23 kilometers. The season is spring with ground reflection user defined as 0.35. Receiver direction cosines are user defined as X = 0.866, Y = 0.866, Z = 0.866.

The data card contains the following:

MODEL = 1

IHAZE = 1

ITYPE = 1

ISEASN = 1

VIS = 0.

W1A = 1000.

T1A = 0.

IPOSIT = 0,.866,.866,.866 (0 specifies user defined followed by input values)

IALBEDO = 0,.35 (0 specifies user defined followed by input value)

H1 = 7.

H2 = 7.

RANGE = 10.

Output is on the following page.

INPUT PARAMETERS...

WEAPON YIELD IS 1000. KILOTONS

HORIZONTAL PATH, ALTITUDE = 7.000 KM, PATH LENGTH = 10.000 KM

HAZE MODEL = 23.0 KM VISUAL RANGE AT SEA LEVEL

MODEL ATMOSPHERE 1 = TROPICAL

HAZE MODEL 1 = RURAL VIS = 23.0 KM

SEASON = SPRIG SUMM

GROUND REFLECTION IS FROM USER DEFIN

RECEIVER DIRECTION COSINES ARE X = 0.866 Y = 0.866 Z = 0.866

VERTICAL PROFILE AEROSOL MODEL = STRAT BKGR

OUTPUT PARAMETERS...

AT THE SOURCE...

IR THERMAL YIELD IS 197.81 KILOTONS

VISIBLE THERMAL YIELD IS 153.49 KILOTONS

UV THERMAL YIELD IS 51.98 KILOTONS

TOTAL THERMAL YIELD IS 408.53 KILOTONS

AT THE RECEIVER...

IR UNREACTED FLUENCE IS 11.33 CAL/CM2

VISIBLE UNREACTED FLUENCE IS 9.22 CAL/CM2

UV UNREACTED FLUENCE IS 1.91 CAL/CM2

TOTAL UNREACTED FLUENCE IS 22.46 CAL/CM2

SCATTERED FLUENCE IS 7.84 CAL/CM2

REFLECTED FLUENCE IS 3.83 CAL/CM2

TOTAL FLUENCE ON TARGET IS 34.12 CAL/CM2

Problem 5

The fifth problem is to compute the thermal fluence on target for a 1 megaton weapon with the receiver on the ground and the burst altitute at 4 kilometers. The slant range is 8 kilometers. The 1962 U.S. Standard Atmosphere is to be used with the Urban Aerosol Model. Visual range at sea level is 5 kilometers. The season is summer and ground reflection is from bare ground. Receiver direction cosines are X = .5, Y = 0., and Z = .866.

Data card parameters are:

MODEL = 6

IHAZE = 5

ITYPE = 2

ISEASN = 1

VIS = 0.

W1A = 1000.

T1A = 0.

IPOSIT = 10

IALBEDO = 5

H1 = 0.

H2 = 4.

RANGE = 8.

Output is on the following page.

INPUT PARAMETERS...

WEAPON YIELD IS 1000. KILOTONS

SLANT PATH BETWEEN ALTITUDES H1 AND H2 WHERE H1 = 0.000 KM H2 = 4.00 KM

PATH LENGTH IS 8.000 KM

HAZE MODEL = 5.0 KM VISUAL RANGE AT SEA LEVEL

MODEL ATMOSPHERE 6 = 1962 US STANDARD

HAZE MODEL 5 = URBAN VIS = 5.0 KM

SEASON = SPRIG SUMM

GROUND REFLECTION IS FROM BARE GRND

RECEIVER DIRECTION COSINES ARE X = .500 Y = 0.000 Z = .866

VERTICAL PROFILE AEROSOL MODEL = STRAT BKGR

OUTPUT PARAMETERS...

AT THE SOURCE...

IR THERMAL YIELD IS 200.66 KILOTONS

VISIBLE THERMAL YIELD IS 155.71 KILOTONS

UV THERMAL YIELD IS 52.73 KILOTONS

TOTAL THERMAL YIELD IS 414.42 KILOTONS

AT THE RECEIVER...

IR UNREACTED FLUENCE IS 3.33 CAL/CM2

VISIBLE UNREACTED FLUENCE IS 1.03 CAL/CM2

UV UNREACTED FLUENCE IS .07 CAL/CM2

TOTAL UNREACTED FLUENCE IS 4.43 CAL/CM2

SCATTERED FLUENCE IS 2.61 CAL/CM2

REFLECTED FLUENCE IS 0.00 CAL/CM2

TOTAL FLUENCE ON TARGET IS 7.04 CAL/CM2

Problem 6

The sixth and last example problem illustrates special case one mentioned in the LOWTHRM User's Guide. In this problem, specific meteorological data is used for a horizontal path at 10 kilometer height. The weapon yield is 1 megaton with a path length of 10 kilometers. The Rural Aerosol Model is used with a sea level visibility of 50 kilometers. The season is fall. The receiver direction cosines are X = 1., Y = 0, and Z = 0. Ground reflection is from desert. Pressure is 1000 millibars, ambient temperature is 10°C, relative humidity is 40%, and the Midlatitude Winter Ozone profile is to be used.

The data card parameters are:

MODEL = 0

IHAZE = 1

ITYPE = 1

ISEASN = 2

VIS = 50.

W1A = 1000.

T1A = 0.

IPOSIT = 1

IALBEDO = 1

H1 = 10.

H2 = 10.

RANGE = 10.

A second data card is used for this problem. It contains values for target height (km), pressure (mb), temperature (Deg. C), Dew Point temperature (Deg. C), percent relative humidity, water vapor density ($gm/m^3$), ozone density ($gm/m^3$), and path length (km). In this case the parameters are as follows using format 429 found in Subroutine NSMDL:

Target height = 10.

Pressure = 1000.

Temperature = 10.

Dew Point temperature = 0. (Default value is computed)

Percent relative humidity = 40.

Water Vapor Density = 0. (Not used in this problem)

Ozone Density = 0. (Midlatitude Winter profile used--see below)

Path length = 10.

Since the Midlatitude Winter Ozone profile is to be used, a source program card substitution is required. The user must remove the card "M3 = 0" from the program and add "M3 = 3" to load the appropriate values.

Output is essentially the same as before. The line specifying model atmosphere selected is not printed when MODEL is set to zero. For this problem the output is on the following page.

INPUT PARAMETERS...

WEAPON YIELD IS 1000. KILOTONS

HORIZONTAL PATH, ALTITUDE = 10.000 KM, PATH LENGTH = 10.000 KM

HAZE MODEL = 50.0 KM VISUAL RANGE AT SEA LEVEL

HAZE MODEL 1 = RURAL VIS = 50.0KM

SEASON = FALL WINTR

GROUND REFLECTION IS FROM DESERT

RECEIVER DIRECTION COSINES ARE X = 1.000 Y = 0.000 Z = 0.000

VERTICAL PROFILE AEROSOL MODEL = STRAT BKGR

OUTPUT PARAMETERS...

AT THE SOURCE...

IR THERMAL YIELD IS 198.82 KILOTONS

VISIBLE THERMAL YIELD IS 154.28 KILOTONS

UV THERMAL YIELD IS 52.24 KILOTONS

TOTAL THERMAL YIELD 410.63

AT THE RECEIVER...

IR UNREACTED FLUENCE IS 11.29 CAL/CM2

VISIBLE UNREACTED FLUENCE IS 10.45 CAL/CM2

UV UNREACTED FLUENCE IS 1.61 CAL/CM2

TOTAL UNREACTED FLUENCE IS 23.35 CAL/CM2

SCATTERED FLUENCE IS 7.49 CAL/CM2

REFLECTED FLUENCE IS .83 CAL/CM2

TOTAL FLUENCE ON TARGET IS 31.67 CAL/CM2

## VITA

Chris Roland Westbrook was born on 12 November 1950 in Converse, Louisiana. He graduated from high school in Shreveport Louisiana in 1968 and attended the University of Tennessee from which he received the degree of Bachelor of Nuclear Engineering in August 1973. After completing Officer Training School in December 1973, he was commissioned in the USAF. Upon completion of missile training in May 1974, he served as a Titan II crew commander and Wing Instructor in the 374th Strategic Missle Squadron and the 308th Strategic Missile Wing at Little Rock AFB, Arkansas until entering the School of Engineering, Air Force Institute of Technology, in August 1978.

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A Fortran computer program LOWTHRM is described for calculating nuclear thermal fluence incident upon a target area. Atmospheric transmissivity factors in the spectral region 0.25 to 28.5 microns are determined through use of the LOWTRAN5 computer code. The program provides a choice of six model atmospheres covering seasonal and latitudinal variations from sea level to 100 km, eight haze models, and accounts for molecular absorption, molecular scattering, and aerosol extinction. Atmospheric refraction, earth curvature

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effects, thermal scattering, and thermal ground reflection contributions are included.